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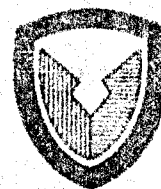
METHOD FOR DETERMINING THE CENTER OF MASS OF HELMETS

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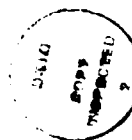
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Center of Mass (CoM) of Helmets effects their performance. This report introduces a simple device capable of determining the CoM of symmetric, asymmetric, or irregular objects. A technique for describing the CoM of helmets is described and shown.		

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METHOD FOR DETERMINING THE CENTER OF MASS OF HELMETS

INTRODUCTION

Protective helmets are intended to reduce mortality and injury resulting from impact to the head. There is, however, increasing evidence that the helmet, worn to provide protection from direct impact, may actually contribute to head and neck injury in indirect impact (hyperflexion or "whiplash") by increasing rotary acceleration.¹ In either circumstance (impact or acceleration) the design of the helmet, by virtue of the location of its Center of Mass (CoM), can serve to improve its protective characteristics or contribute to head/neck injuries.

In the Military, the helmet has been assigned a multi-functional role. In addition to providing protection against impact or blunt trauma, it must now provide ballistic protection as well as support ancillary equipment such as communications (earcups, headset, and microphone), faceshield or visor, night vision goggles, and other sighting devices. These expanded functions of the helmet in a highly mobile activity, place increased emphasis on helmet design with respect to weight and the location of the CoM. The addition of functional modules compound the problems of weight distribution by increasing torque loads to the head and neck. Weight distribution also affects comfort during prolonged wear.

This study presents a technique for determining the CoM of helmets, and the effective position change of the CoM of the head when a helmet is donned. The technique for determining CoM is also applicable to asymmetrical objects.

CENTER OF MASS (CoM) OR CENTER OF GRAVITY (CoG)

Center of Mass is that point in a body or system through which any plane bisects the mass moments. About that point, a body or system can rotate and remain in equilibrium under the earth's gravitational pull. The CoM is that point at which the mass of the body or system may be considered to be concentrated.

The gravitational pull on a body is not uniform, that is, it varies with the distance from the center of the earth; thus the top of an object is subjected to less gravitational force than the bottom. An asymmetrical body or system will not be in equilibrium around the CoM; it will be in equilibrium around the Center of Gravity (CoG), that point at which the gravitational moments are in equilibrium.

In our studies we actually locate the Center of Gravity. The differences in distances between helmet surfaces and masses involved are so relatively small when compared with the distance

to the center of the earth and its mass, that the Com and Cog are virtually indistinguishable and may be used interchangeably. Since we are concerned with weight, forces, and moments, we shall identify the equilibrium point that we locate as the Center of Mass.

The Mass and CoM of the human head vary among individuals. These parameters cannot be measured on living human subjects. The criteria used are usually documented from determinations made on cadaver heads using various measuring techniques.^{2,3,4} For this study, the head was assumed to weigh 10 pounds (4536 g) with its CoM located at the point where a line between the tragii intersects the midsagittal plane.

HELMETS EVALUATED

a. Military

- (1) Helmet, Flyer's SPH-4
- (2) Helmet, Combat Vehicle Crewman DH-132
- (3) Helmet, Ground Troops, Parachutist, PASGT
- (4) Helmet, Ground Troops Parachutist, PASGT w/visor and Communications equipment
- (5) Helmet, Combat, M-1 w/liner

b. Civilian

- (1) PSH-77 Safety Helmet, (Swiss Titanium Helmet)
- (2) Helmet, Bomb Disposal, Protective Materials Co., Inc., Model No. 920
- (3) *Helmet, Bomb Disposal, Gault Glass Laminates Ltd, Isle of Wight, Model MK-11
- (4) Bell: Moto-Star II Motorcyclist Helmet
- (5) Bell: Moto-3 Motorcyclist Helmet
- (6) Bell: RT6 Motorcyclist Helmet
- (7) Shoei: SR-G Motorcyclist Helmet
- (8) Shoei: Super-Sport Hawk Motorcyclist Helmet
- (9) Shoei: Hawk Motorcyclist Helmet

*Conforms with United Kingdom Purchase Description No. SCRDE/PD1/74C.

CoM/CoG LOCATING APPARATUS

Locating the CoM/CoG of a helmet may be accomplished by suspending it (helmet) from one point and then another. The CoM will then hang under each suspension point. Lines dropped from each suspension point will intersect at a common point -- the CoM. A variety of instruments and techniques have been used for locating the CoM of irregular and asymmetric bodies.^{3,4,5} A device was developed specifically to locate the CoM of a helmet.⁶ This mechanism was comprised of a headform, counterweights, a protractor, and a torque wrench that was used to balance the headform and helmet. Data derived from balancing the mechanism were then used to calculate the position of the CoM. This device was difficult to balance and the results were unreliable.

Natick R&D Center developed a simple device that would locate the CoM of a helmet; it was based on the principle that a free moving body will rotate around its CoM (Fig. 1). If a helmet was permitted to rotate about a horizontal axis, it would turn and come to rest with the greater mass on the bottom (closer to the earth's center). If the helmet were adjusted so that it would rest in any position about the axis, the axis of support would then pass through the CoM. In a bilaterally symmetrical object, the CoM would be at the intersection of its bisecting plane and the equilibrium axis perpendicular to it. The CoM of an asymmetrical or irregular object would be determined by the intersection of any two equilibrium axes.

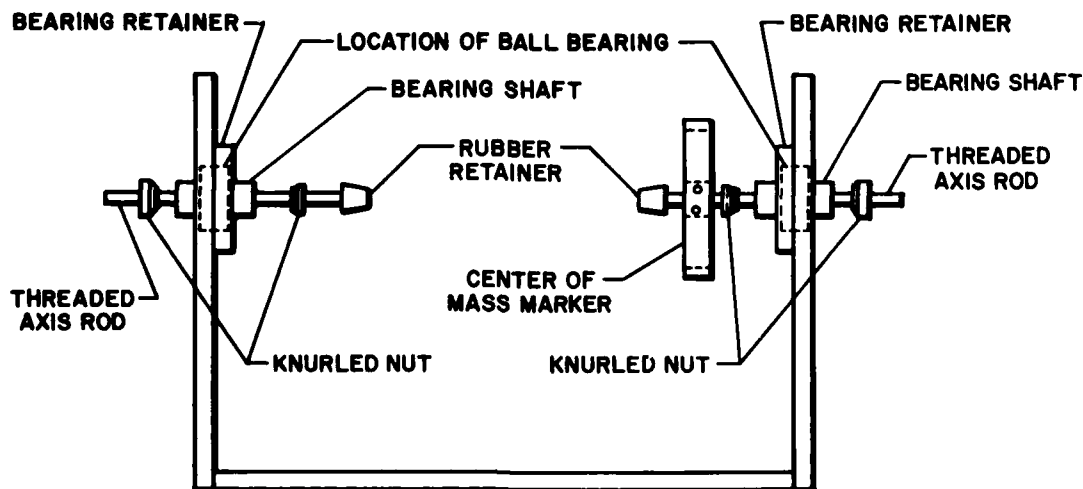
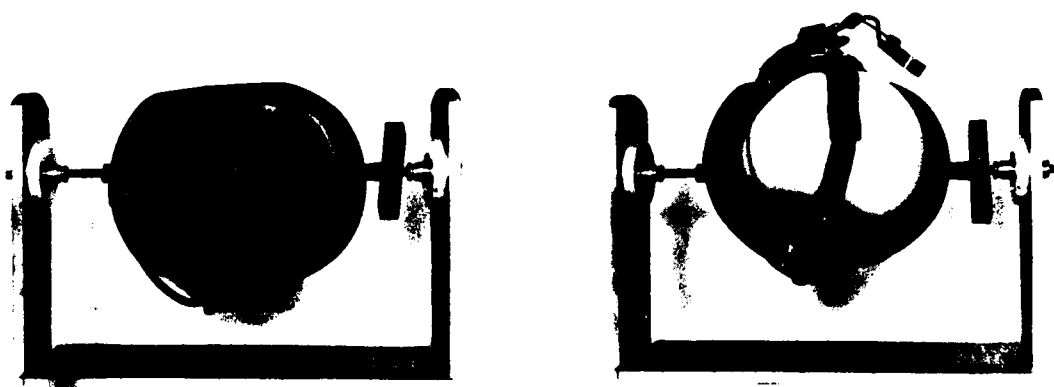


Figure 1. Center of Mass locating device developed at
US Army Natick R&D Center

Floating chinstraps, suspension bands, and earflaps present a variable that, if not controlled, would preclude placing a helmet assembly into equilibrium. To stabilize and fix the chinstraps, nape straps, suspension bands, and ancillary equipment in an "as worn" position, a balloon was inflated inside the helmet to simulate the configuration of the head. The weight of the balloon was uniformly distributed and was negligible as compared with the weight of the total helmet assembly (less than 0.1%). See Fig. 2.



Unsupported

Simulated as worn

Figure 2. Balloon simulates head to stabilize helmet's flexible suspension, chinstrap, and ancillary equipment in determination of Center of Mass.

METHOD AND RESULTS

a. Each helmet to be evaluated was first adjusted to fit a Medium size anthropometric headform.⁷ The helmet was then seated and adjusted on the headform in an as-worn mode. Distances from a baseline to the front and rear centers of the helmet edge (Fig. 3) were measured and noted. These data will serve to reposition the helmet later in the study.

b. The helmet was then placed in the CoM locating apparatus perpendicular to its bisecting plane and adjusted until equilibrium was achieved. The poles of the axis were marked on the helmet shell.

Since the helmet was symmetrical or near symmetrical,* the CoM would be that point where the axis of the balanced helmet intersected the bisecting plane. This procedure was repeated with the helmet in each potential mode of use -- with visor up, down, or removed.

c. The helmet was again positioned on the headform to conform with the previously noted locating points (para a. above). Vertical and horizontal coordinates of the CoM of the headform and the helmet were determined with relation to fixed positions previously measured (Fig. 4).

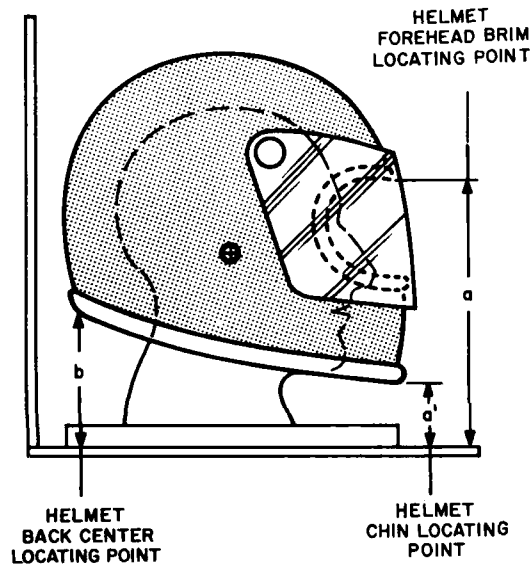


Figure 3. Locating points on symmetrically positioned helmet.

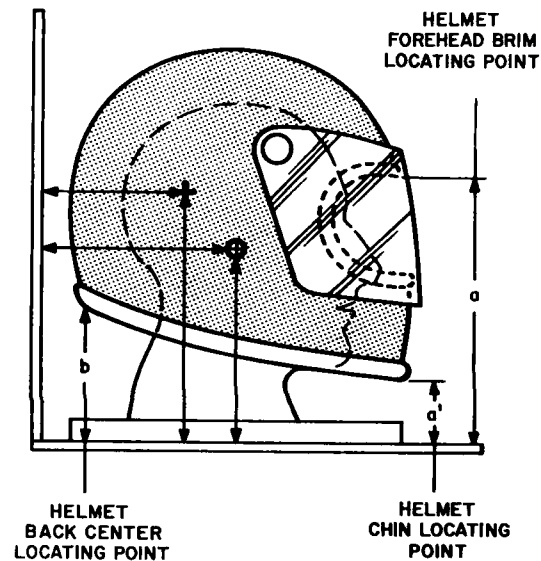


Figure 4. Locating points used in determining Center of Mass

d. When a helmet is donned, unless its CoM is coincident with the CoM of the head, the CoM of the head will shift towards the CoM of the helmet. The magnitude of the shift will be a distance from the head that is in proportion to the distance between the

*Those helmets with communication equipment had a microphone on one side and a switch on the other. These approximated equivalent masses and were considered as such.

CoM of the head and the CoM of the helmet as the mass of the head is to the mass of the head-helmet assembly (Fig. 5). Fig. 6, 7, and 8 are scaled schematics showing the CoM of each helmet in relation to the CoM of the helmet. Table 1 defines the calculated location of the CoM of the head, when each helmet is worn, in terms of the angle of rotation and the radius.

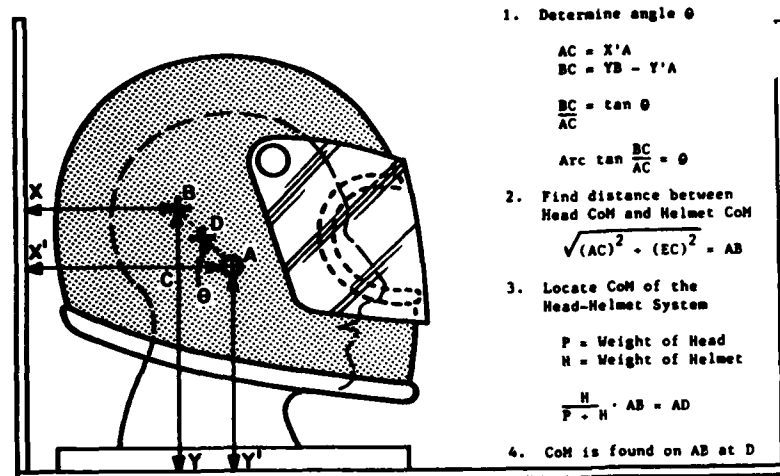
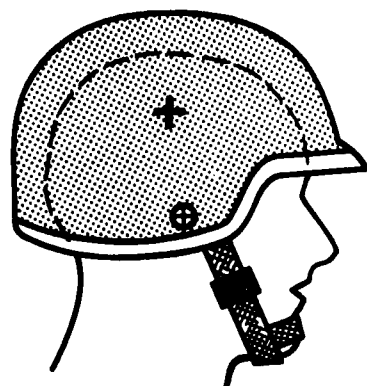
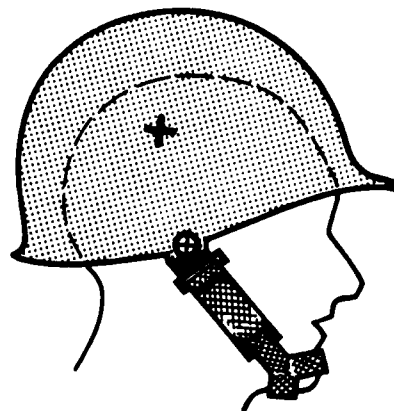


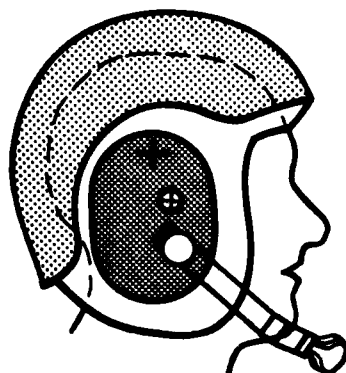
Figure 5. Locating the Center of Mass (D) of the Head-Helmet System.



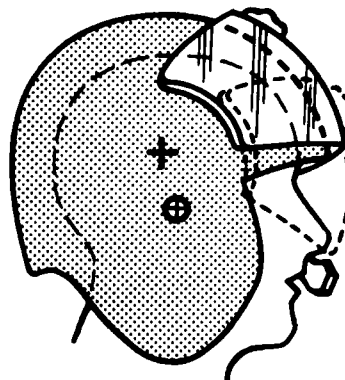
HELMET, PARACHUTIST, PASGT



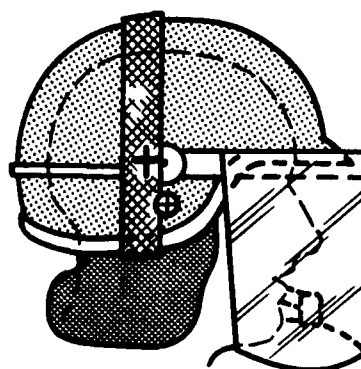
HELMET, COMBAT, M-1 w/LINER



HELMET
COMBAT VEHICLE CREWMAN DH-132

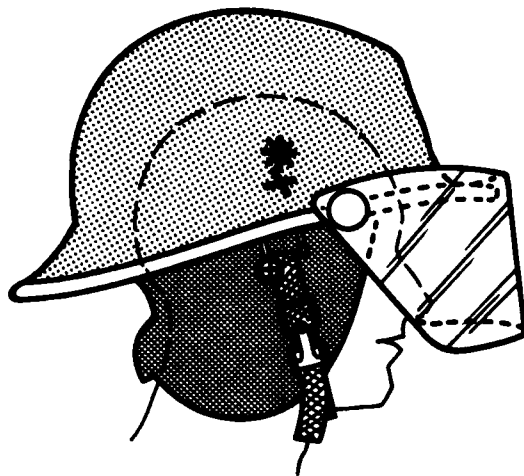


HELMET, FLYER'S SPH-4

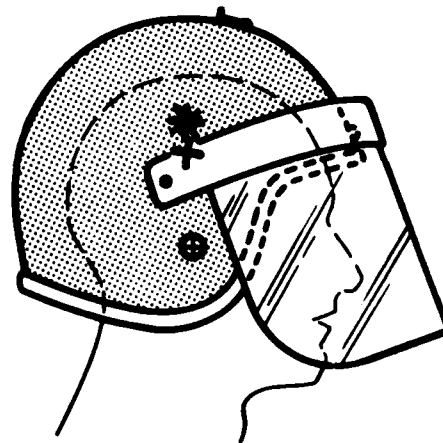


HELMET, PARACHUTIST, PASGT w/FACE
SHIELD AND COMMUNICATIONS EQUIPMENT

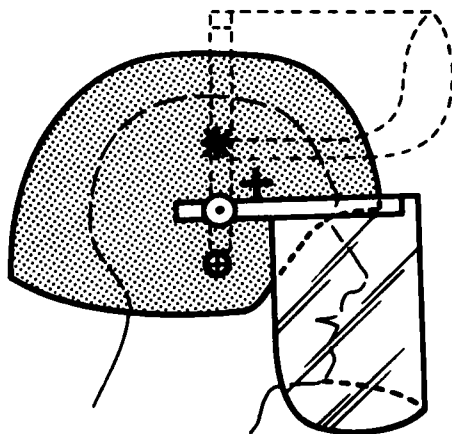
Figure 6. Center of Mass of military helmet (+) in relation to the Center of Mass of the head (@).



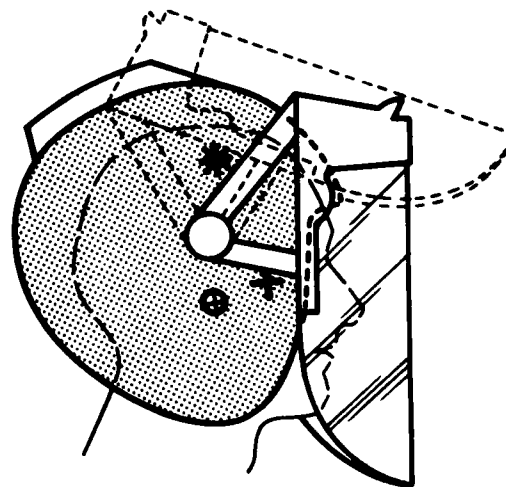
HELMET, FIRE FIGHTER



PSH-77 SAFETY HELMET
(SWISS HELMET)

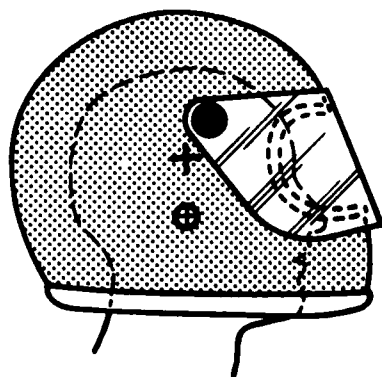


HELMET,
BOMB DISPOSAL,
MODEL NO. 920

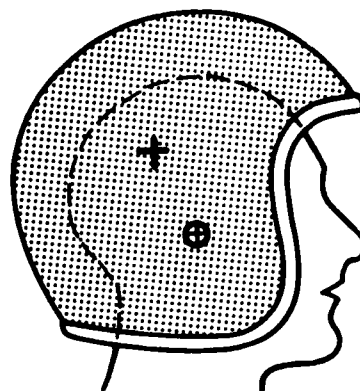


HELMET,
BOMB DISPOSAL,
MODEL MK-II

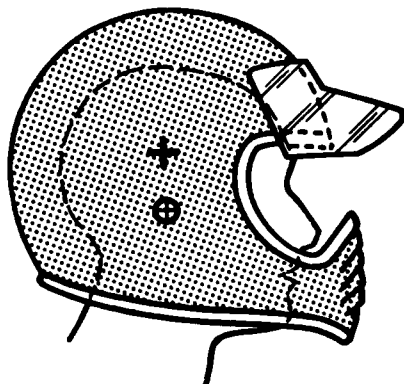
Figure 7. Center of Mass of safety helmets, with shields raised (*) and lowered (+), in relation to the Center of Mass of the head (O).



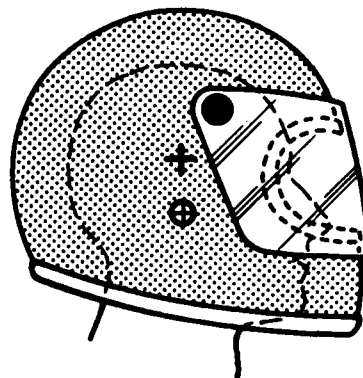
BELL: MOTO-STAR II



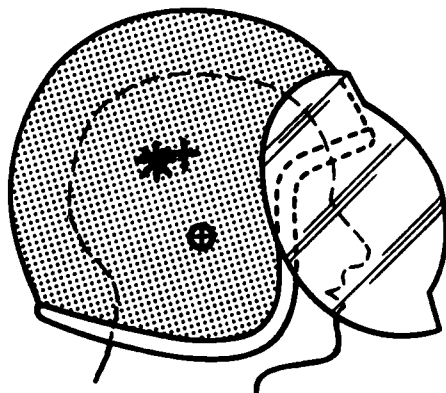
SHOEI: SR-G



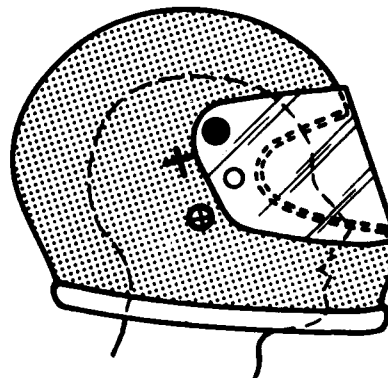
BELL: MOTO-3



SHOEI: HAWK



BELL: RT6



SHOEI: SUPER-SPORT HAWK

Figure 8. Center of Mass of motorcyclist helmets with faceshield attached (+) and removed (*), in relation to the Center of Mass of the head (O).

TABLE 1. Center of Mass for Military and Civilian Helmet (Head) Combinations.

	Basic Helmet				Helmet w/Visor Down				Helmet w/Visor Up			
	Dist from CoM of Head		Dist from CoM of Head		Dist from CoM of Head		Dist from CoM of Head		Dist from CoM of Head		Dist from CoM of Head	
	Wt g	degrees	Helmet cm	Head/ Helmet cm	Wt g	degrees	Helmet cm	Head/ Helmet cm	degrees	Helmet cm	Head/ Helmet cm	degrees
Military												
PASGT	1650	72.1	3.29	1.04								
*PASGT (MOD)	2186	47.7	4.01	1.30	2430	72.2	3.38	1.17				
*Flyer's, SPH-4					1477	79.3	3.73	0.91				
*CVC, DH-132	1503	62.7	3.63	0.91								
M-1 Shell & Liner	1452	72.8	7.72	1.88								
Safety												
Firefighter					1276	96.8	5.51	1.22	41.9	6.76	1.47	
PSH-77 (Swiss)	1815	69.4	6.60	1.88	2835	88.6	5.92	2.29	82.0	7.26	2.78	
EOD Model 920	2940	80.2	7.74	2.92	3827	113.8	5.11	2.34	93.3	8.23	3.76	
EOD Model MK II	2364	62.6	4.83	1.66	4735	156.6	4.32	2.21	100.0	8.15	4.17	
Motorcyclist												
Bell MOTO STAR II					1800	87.5	4.14	1.22				
Bell MOTO 3	1480	76.9	4.04	0.99	1537	84.5	4.17	1.07				
Bell RT-6	1219	65.4	5.69	1.19	1350	80.6	5.21	1.19				
Shoei SR-G	1441	71.9	5.61	1.27								
Shoei Super Sport Hawk					1500	83.7	3.79	0.84				
Shoei Hawk					1670	91.4	4.01	1.07				

*Includes communication equipment.

CONCLUSIONS

The Center of Mass of helmets and other protective gear has always been a concern for the designer. At best, the CoM of a clothing item was located and adjusted by subjective evaluations. Verification of acceptable location of the CoM may have been accomplished by human factors performance studies or ergonomic stress studies. The CoM locating device presented herein can be effectively applied to soft and flexible artifacts, such as clothing, as well as to rigid asymmetrical bodies. Below, a boot demonstrates how the CoM device may be used with an asymmetrical system. A balloon is placed in the upper quarter (shaft) of the boot to set it in an as-worn configuration to locate the CoM.

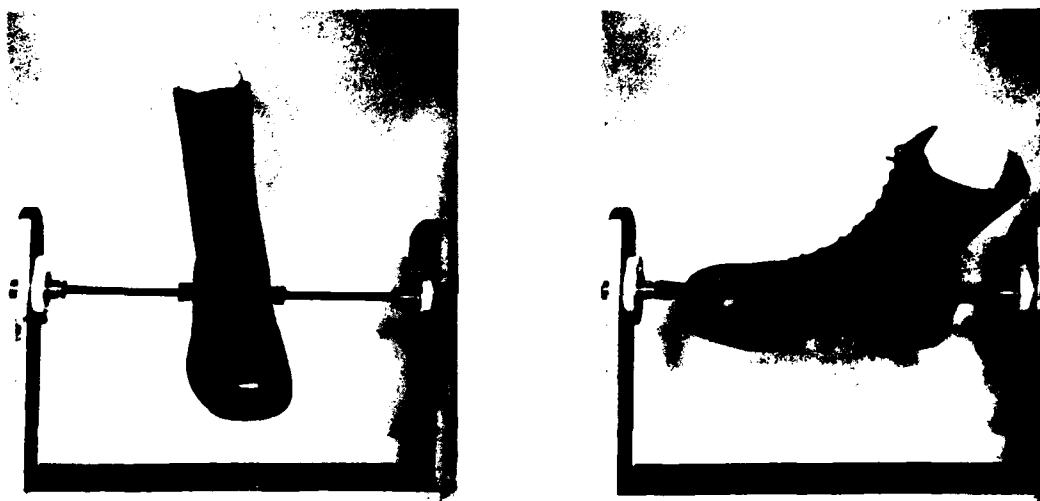


Figure 9. Balloon simulates foot to stabilize military boot in determination of Center of Mass

The locating device provides a low-cost, versatile design and quality control device that requires no special skills or knowledge to operate.

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